BAA 10-28 (Software)
BAA 10-29 (Hardware)

Industry Day
18 February 2010

Dr. Robert Mandelbaum

Program Manager

DARPA IPTO/TTO

AGENDA

12:00 Check-in

13:00 ARM Program Brief - Dr. Robert Mandelbaum, ARM Program Manager

14:00 ARM BAA - Mr. Stephen Davis, DARPA CMO

14:30 Break

15:00 Q&A Session

16:00 Adjourn

ARM Program Vision

Countermine

Search & Rescue

Weapons Support

Checkpoint

EOD

Put robotic utilization on exponential growth path

Automating prosthetics

Casualty Care

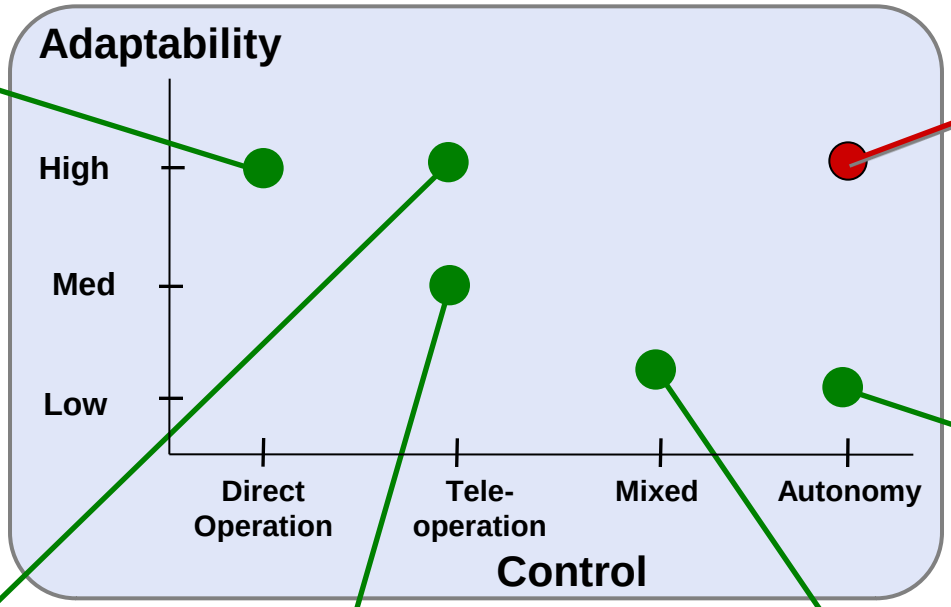
Extreme Environments

Take the human out of the loop, and make it faster.
Operate in areas with bad comms, extreme danger, or manpower shortages
Reduce operator workload, bandwidth, training time, hardware complexity

State of the Art

Prosthetic Arm

- Direct interface to nervous system



ARM Goal

Military / EOD

- No force or touch feedback
- Joint-by-joint control

Robonaut

- Full immersion tele-operation

Planetary

- Simple scooping only

Manufacturing

- Structured environments only

Current systems require burdensome human operation, and high-precision arms and hands, yet a 2-year old child manipulates better

ARM Program Motivation

We put people in danger every day, because sometimes hands are the only tools that work -- particularly in situations that need high resilience, flexibility, and adaptability.

The ARM program will enable military applications that can revolutionize the battlefield by making robots just as dexterous, resilient, and flexible.

Autonomous manipulation with a pair of mechanized arms/hands enables effective unmanned applications

Challenge Tasks

The ARM program will culminate in three demonstrations:

1. GYM BAG

Open a gym bag, search through contents, and pick up the revolver inside

2. RUBBLE

Pick up and move large, irregular object

3. MORTAR

Load shell into mortar

Successful completion of these challenges illustrates mastery of the basic competencies required of adaptive manipulation:

1. handling non-rigid objects,
2. manipulating large, irregular objects, and
3. guiding an object relative to another object

Technical Challenge

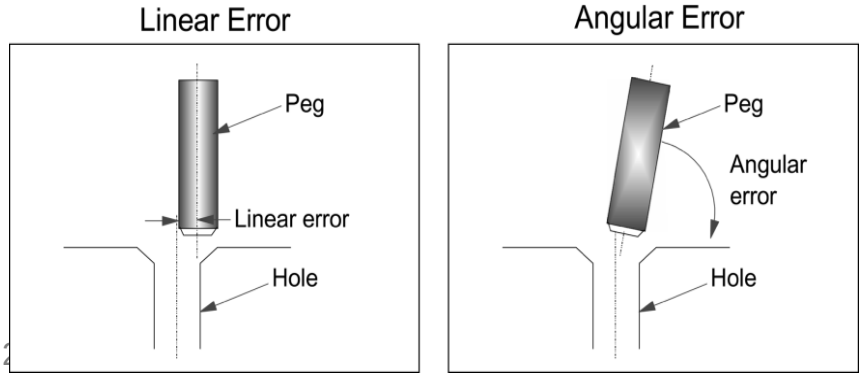
Manipulation requires many degrees of freedom (dof), and the results of contact are inherently unpredictable

Dimensionality

- Car 2-dof (steer, accelerate)
- BigDog 16-dof (4 x 4-dof legs)
- Pick Up Pen 32-dof

Contact Models

- Newton's laws can predict the outcome of physical interactions – Seems easy
- But motions are not performed or known exactly, so geometry is uncertain
- And forces are not applied exactly, so dynamics are uncertain
- And material properties (friction, stiffness) of real objects not uniform or well-known
- Soon, error bars swamp the knowns – Not so easy anymore!



Uncertainty is the key issue
Adaptability is key

Factoring the Problem

Perception, cognition, and feedback control to plan and execute complex interactions in an unstructured and dynamic world

Software

Perception

- Determine object shape and pose using vision and/or touch
- Identify material properties with touch
- Monitor task progress using force and vision feedback (drilling, turning screw, …)

Grasping

- Plan and control reach, contact, closure with noisy sensing in a complex environment
- Evaluate grasp quality
- Handle novel objects

Manipulation

- Perform work tasks (assembly, disassembly, insertion)
- Task execution despite significant contact dynamics and environmental disturbances (action changes object, task)

Mobile Manipulation

- Pose planning subject to task / maneuver constraints (opening door)
- Interact in real world with occlusions and non-optimal perspectives

Hardware

Low-Cost Hand

- Sufficient compliance, strength, controllability using loose mechanical tolerances
- Tactile sensing on fingers, force sensing at joints

Program Concept

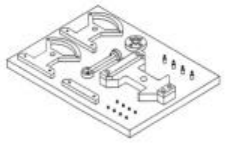
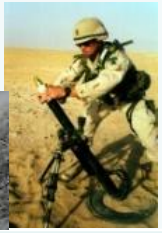
- **Three tracks:**
  - ARM-S to develop software to solve autonomous manipulation tasks
  - ARM-H to develop low-cost hands to perform same tasks
  - Outreach track to provide community at large access to GFE platforms

- **Software testing structure:**
  - Performers develop software using GFE platforms.
  - Evaluation team maintains separate GFE platform
  - At regular intervals, performers send latest software
  - Testing performed at evaluator's site on Gvt. platform; performers observe via web/phone.

- **Hardware testing structure:**
  - Performers develop manipulator and an interface for direct human control.
  - Evaluation team incorporates manipulator into GFE platform.
  - Manipulator evaluated using human controller

- **ARM-H manipulator incorporated into GFE to evaluate ARM-S portability**

Challenge Tasks by Phase

	Phase 1 – 15 months Grasping and manipulation	Phase 2 – 15 months Complex grasping and bimanual manipulation	Phase 3 – 18 months Mobile bimanual manipulation in real-world
Grasping	G1    	G2   	G3  
Manipulation	M1   	M2 (bimanual)    	M3 (bimanual)   
Mobile Manipulation			MM3  

- *Same tasks for both software and hardware tracks*
- *TENTATIVE. SUBJECT TO CHANGE. EXAMPLES*

Software Track

Focus: *Grasp and Manipulate known objects without direct human control*

Software track: Vertical integration

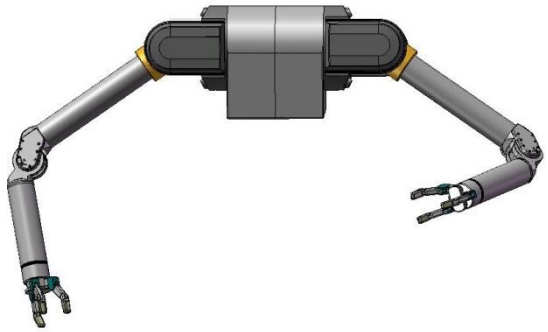
- Teams to include specialists in perception and manipulation
- Each team provided with GFE arms, hands, and sensor head
- Object category (e.g., grenade) and object shape (CAD file) is provided in early phases
- Teams develop component competencies over increasingly difficult challenge tasks (G1, G2, G3, M1, M2, M3)
- **Metrics:** Task success percentage, Task completion time
- **Final challenges:** require integrating all prior competencies for GYM BAG, RUBBBLE, and MORTAR demonstrations.

Incremental challenges	Phase 1	Phase 2	Phase 3
Grasping tasks	**G1:** Rigid objects (e.g., rocks)	**G2:** Articulated objects (e.g., pliers), non-rigid (e.g., uniform)	**G3:** Complex objects (e.g., handle of ammo box)
Manipulation tasks	**M1:** Single hand acts on simple system (e.g., turn key)	**M2:** Bimanual holding and acting (e.g. unzip gym bag)	**M3:** Two-handed forceful operations (e.g., shovel)

GFE for Software Track

TENTATIVE for Phase 1. LIKELY to change in Phases 2 and 3. Software must adapt to different hardware

Arm & Hand



WAM (Barrett, 7 dof,
F/T sensor)

3-fingered hand
(Barrett, tactile sensors for tips and palm)

Head

Swiss Ranger 4000
- 176x144 at 54 fps

Bumblebee 2
- 648x488 at 48 fps

Color camera
- 5 MP, 45 deg FOV

Stereo microphones
- 44 kHz, 16-bit

Neck: Pan, tilt, translate along shoulder-shoulder axis

Mobile Base

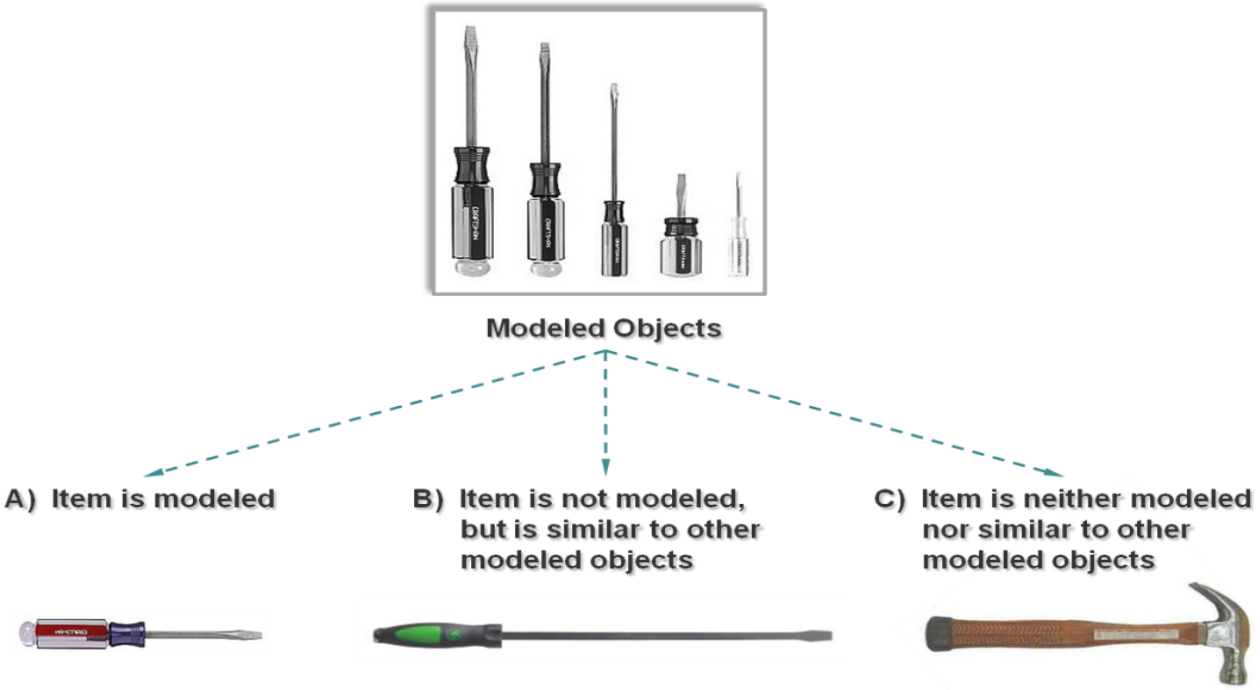
Not selected yet
Likely will include torso DOFs
Likely run on wheels with batteries

System Integration

Robotics Engineering Excellence (RE2) responsible for integrating all pieces into single system and providing APIs, training

GFI for Software & Hardware Tracks

- DARPA will provide as GFI a three-dimensional model of each category of object
  - Model will specify at least the three-dimensional shape of the object
  - Perhaps other attributes such as mass distribution
- Begin with Case A (below), progress to Case B, Probably not address Case C



ARM-S Test Procedure

- **Frequent evaluations begin 2 months after Kickoff**
- **Held at ARM Evaluation Facility (AEF), Arlington, VA**
- **Executed by the ARM Evaluation Team (AET)**

- **Evaluation Process**
  - Team uploads code to AGT prior to test day
  - Team schedule for time slot xxx
  - Continuous video streaming from AEF to team being tested
  - AET establishes voice telecon link with scheduled team
  - ARM GFE set to starting position
  - Series of objects are grasped/manipulated
  - Disconnect – repeat for next team slot
  - Following day, Log data from each team's evaluation is posted

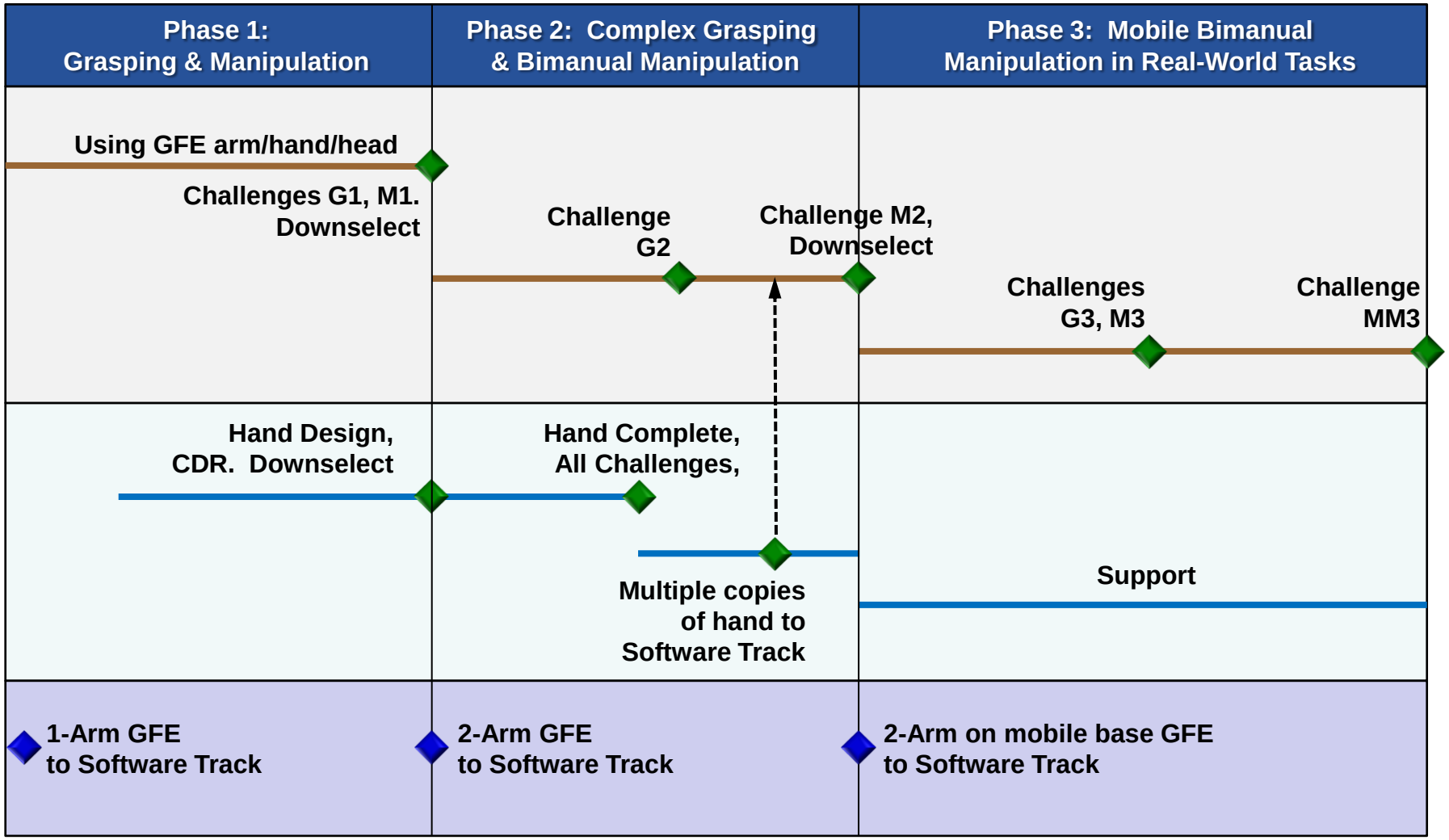
Hardware Track

Replace expensive, complex hardware with cheap feedback control

Design & Build manipulator

- **Motivation:** Enable transition – low cost
- Teams design and build rugged manipulator at low manufacturing cost to replace claw-like three fingers
- **Metrics:** Low cost, Performance on challenge tasks (G1, M1, G2, M2, G3, M3) with human operator.
- **Final challenges:** Human operator performs GYM BAG, RUBBLE, and MORTAR demonstrations.

Schedule



Outreach Track

- In addition to the core ARM research program, DARPA will sponsor an Outreach Track
  - Opportunity for unfunded, external participant involvement
  - DARPA provides:
    - Hardware
    - Interface for remote development, porting, testing of code
    - Test environment
    - Technical support
  - Targeted participants
    - Students/educational institutions
    - Average citizen/hobbiest
    - Interested corporate teams

- **General participant outreach** (4Q FY10)
  - Global usage of user-developed code in identical ARM test environment
  - Opportunity for general community to develop code similar to funded teams
  - Focused public events (FIRST-type competitions)
- **Artistic outreach** use (4Q FY11)
  - Museum events for general community use (e.g. creation of “techno-art”)
  - Ability to see technology and result in a public forum

Per ARM-S BAA-10-28 – Funding Info

- **For planning purposes, DARPA estimates, as a preliminary point of departure, the following duration and number of teams for each phase of the Software Track (subject to change):**
  - Phase 1: 15 months, up to 6 teams
  - Phase 2: 15 months, up to 4 teams
  - Phase 3: 18 months, up to 2 teams

- **For planning purposes, DARPA estimates funding levels of approximately:**
  - $0.75M-$1.25M per team in Phase 1
  - $1.25M-$1.75M per team in Phase 2
  - $1.75M-$2.25M per team in Phase 3

Refer to BAA-10-28 for all ARM-S info on funding and disclaimers

Per ARM-H BAA-10-29 – Funding Info

- **For planning purposes, DARPA estimates, as a preliminary point of departure, the following duration and number of teams for each phase of the Hardware Track (subject to change):**
  - Phase 1: 12 months, up to 3 teams
  - Phase 2: 15 months, up to 1 team
  - Phase 3: 18 months, up to 1 team

- **For planning purposes, DARPA estimates funding levels of approximately:**
  - $0.50M-$0.75M per team in Phase 1
  - $2.0M-$2.5M per team in Phase 2
  - $0.25M-$0.50M per team in Phase 3

Refer to BAA-10-29 for all ARM-H info on funding and disclaimers

Proposal - Things to avoid

- Systems integrators who don't do the scientific "heavy lifting"
  - Funding levels only can support small groups
- Unrealistic ARM-S collaborations
  - Close collaboration of team based on extensive GFE use
  - Only one GFE system provided per team
- Critical references to unpublished, "proprietary" technology
- Exceeding the cost guidelines
- Submissions after the initial closing
  - ARM-S Proposals due Friday 19 March 2010
  - ARM-H Proposals due Tuesday 23 March 2010

Program Overview

- Grasp and Manipulate known objects without direct human control
- Perception, cognition, and feedback control to plan and execute complex interactions in an unstructured and dynamic world
- Replace expensive, complex hardware with cheap feedback
- Program success through execution of challenge tasks
    1. Gym Bag - handling non-rigid objects
    2. Rubble - manipulating large, irregular objects
    3. Mortar - guiding an object relative to another object
- ARM-S Proposals due Friday 19 March 2010
- ARM-H Proposals due Tuesday 23 March 2010

ARM-S and ARM-H BAA Process

DARPA/CMO

The BAAs posted at FBO takes precedence over any information contained herein.

BAA PROCESS

Solicitation was released utilizing BAA procedures in accordance with FAR 35.016

- The BAAs were, and any amendments will be, posted in FEDBIZOPPS at www.fbo.gov
- BAAs allow for a variety of technical solutions
- Evaluation of proposals will be accomplished through a scientific review of each proposal using the evaluation criteria stated in each BAA
- Proposals will be due at 1200 NOON (ET) on:
  - **March 19 for ARM-S**
  - **March 23 for ARM-H**
- BAAs cover all info needed to propose.

Following the proposal preparation instructions assists the evaluation team to clearly understand what is being proposed and supports a timely negotiation.

ELIGIBILITY ISSUES

– All interested/qualified sources

– No foreign participants/resources may participate unless authorized by applicable Security Regulations, Export Laws, etc.

– FFRDCs, Government/National labs, military educational institutions, etc. are subject to applicable direct competition limitations and cannot propose to these BAAs in any capacity, unless they can clearly demonstrate the work is NOT otherwise available from the private sector AND they also provide written documentation citing the specific statutory authority establishing their eligibility to propose to Government solicitations.

ITEMS TO NOTE

- Central Contractor Registration (CCR), Online Representations and Certifications Application (ORCA), Employment Eligibility Verification (E-verify) and Wide Area Workflow (WAWF)
- Organizational Conflict of Interest language (SETA vs Performer, IPA)
- Export Control (ITAR) and Publication Approval language
- Subcontracting Issues
  - Subcontracting Plans required for contracts with subcontracting possibilities expected to exceed $550,000, unless offeror is a small business
  - Detailed cost breakdown for subs whose costs are, or exceed, 10% of the total proposed price
  - Appropriate cost or price analyses of subcontractor proposals (FAR 15.404-3)
- Data Rights Assertions - Assert rights to all technical data & computer software generated, developed, and/or delivered to which the Government will receive less than Unlimited Rights. This information is assessed during evaluations.
  - Provide and justify basis of assertions that apply to the Prime and any Subs in the prescribed format.

EVALUATION/AWARD

- No common Statement of Work - Proposal evaluated on individual merit and relevance as it relates to the stated research goals/objectives rather than against each other
- Government reserves the right to select for award all, some, or none of the proposals received and to award without discussions
- Government anticipates making multiple awards
- Funding instruments: procurement contract(s) or Other Transactions Agreements (OTA).
  - OTA for Prototype may be proposed, but must adhere to OTA guidance as outlined at http://www.acq.osd.mil/dpap/Docs/policy/otherTransactions/current%20otguideconformed%20Jan%202001.doc

Only a duly authorized Contracting Officer may obligate the Government

COMMUNICATIONS

- Prior to Receipt of Proposals – No restrictions, however Gov't (PM/CO) shall not dictate solutions or transfer technology
- After Receipt of Proposals – Government (CO) may communicate with offerors in order to understand the meaning of some aspect of the proposal that is not clear or to obtain confirmation or substantiation of a proposed approach, solution, or cost estimate
- Informal feedback may be provided once selection(s) are made
- Questions on the ARM-S BAA should be sent to DARPA-BAA-10-28@darpa.mil
- Questions on the ARM-H BAA should be sent to DARPA-BAA-10-29@darpa.mil

BAA PROCESS

- Proposals must be valid for a minimum of 180 days
- DARPA anticipates unclassified proposals
- DARPA will employ an electronic upload submission system for all responses to these BAAs
- Details/instructions are in the BAAs

Questions?